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High Temperature Deformation and Fracture Behavior of Metals under High Strain Rate Conditions

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by

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I INTRODUCTION

The evaluation of the hot workability of metals and alloys by means of a simple test has been a serious problem for some time. It is, of course, undesirable to be forced actually to forge a sizable piece of metal in order to determine whether or not the conditions applied in terms of temperature and the rate of deformation are the most advantageous. It goes without saying that considerable expense can be avoided by replacing the hot working operation itself by simple tests which disclose the necessary information. We, therefore, are looking for a type of test which gives a maximum of conclusive information and at the same time is fast, simple, and low in cost.

Most forgeability tests commonly used in industry have their drawbacks: compressive and bend tests are limited in the extent of deformation which can be obtained. Also quantitative ductility measurements are difficult to make. In addition, compressive tests suffer from complexities resulting from frictional forces and from insensitivity. Torsion tests, which are easy to perform, suffer from stress and strain gradients in the cross section and are difficult to interpret if cracking is not initiated at the surface. On the other hand, tensile tests offer a rather simple stress system

and high sensitivity with respect to ductility. Unfortunately, with regular tensile tests, only a rather restricted range of strain rates is available.

In previous investigations of the creep behavior of aluminum and some high temperature alloys, it had been shown that the deformation and fracture characteristics followed rather well-defined patterns which are closely related to temperature, strain rate, and composition.

It is the purpose of the present investigation to evaluate the high temperature deformation and fracture behavior of the following materials under high strain rate conditions:

Udimet 500

Tungsten

Beryllium

With laboratory tests from the data obtained, efforts will be made to determine the most pertinent parameters for hot working operations. During the course of the study, various changes in the testing techniques will be incorporated and their effect on the results will be evaluated.

II EXPERIMENTAL TECHNIQUES

For the investigation of hot working characteristics, a modified

constant load creep machine is used. In order to avoid undesirable side effects, loads are applied by means of a double-ended pneumatic cylinder. By the present method, the full load can be applied within 0.02 seconds with no appreciable impact effect. No overload occurs which could, of course, falsify the results. Using specimens of conventional sizes, tests can be conducted at rates up to 20 in/in/sec. A pull rod system is connected to an electro-mechanical device for the purpose of preloading the specimens slightly prior to application of the full load. Time and strain values are recorded automatically with a motion picture camera during the tests.

III RESULTS AND DISCUSSION

Tensile specimens were machined from a cast Udimet 700 ingot (dia. 5 1/2", length 12"). The direction of the specimen axis is identical with the ingot axis. The results of the first set of tests are represented in Table I and Figures 1 through 4. Tests were run at 1900°, 2000°, and 2100° F over a range of strain rates of 0.01 in/in/sec to 5 in/in/sec. All tests were conducted after a minimum soaking time of 10 minutes. The most important set of data is shown in Figure 4, where the reduction in area values are plotted as a function of the rate of deformation. It is evident that the ductility decreases with increasing strain rate.

With strain rates higher than 1 in/in/sec, the ductility is very poor at all temperatures whereas a marked increase can be noted with decreasing strain rate. This increase is most significant with the highest test temperature.

The strain rate dependance of the ductility as demonstrated with Udimet 700 has been found with several multi-phase materials. On the other hand, homogeneous single phase metals showed rather a continuous increase of the ductility with increasing strain rate.

IV FUTURE WORK

The tests on the first set of Udimet specimens will be extended over a wide temperature and strain rate range. The influence of a longer soaking time will be studied.

Whereas the first group of specimens were taken from the outside of the ingot with their axes parallel to the ingot axis, two additional sets will be chosen with the axis perpendicular to the ingot axis (one set from the outside, one set from the center of the ingot).

A metallographic study of the broken specimens has been started and an attempt will be made to correlate microstructural variables with the deformation behavior of the material.

In addition, specimens are being machined from a beryllium hot pressing S-200-C. The direction of the various specimen axes are the same as the ones chosen for the Udimet 700 material and a similar set of experiments will be conducted.

Table I: High Strain Rate Tests on Udimet 700

Code #	Stress p.s.i.	Temp ° F	Life Seconds	El. %	R. A. %	Average Deformation Rate in/in/sec
A-11	80,000	1900	0.020	3.9	2.9	1.950
A-10	60,000	1900	0.492	9.8	11.8	0.199
A-12	45,000	1900	20.895	16.2	24.0	0.008
A-1	75,000	2000	*	1.6	1.9	-
A-2	60,000	2000	0.014	8.6	1.9	6.143
A-3	45,000	2000	0.179	12.0	9.6	0.670
A-4	35,000	2000	1.620	13.6	27.7	0.084
A-5	30,000	2000	4.105	14.0	40.4	0.034
A-8	40,000	2100	*	6.6	1.0	-
A-6	30,000	2100	0.049	13.0	9.6	2.653
A-7	22,500	2100	0.235	28.3	31.8	1.204
A-9	15,000	2100	1.638	37.5	64.0	0.229

*No time recorded

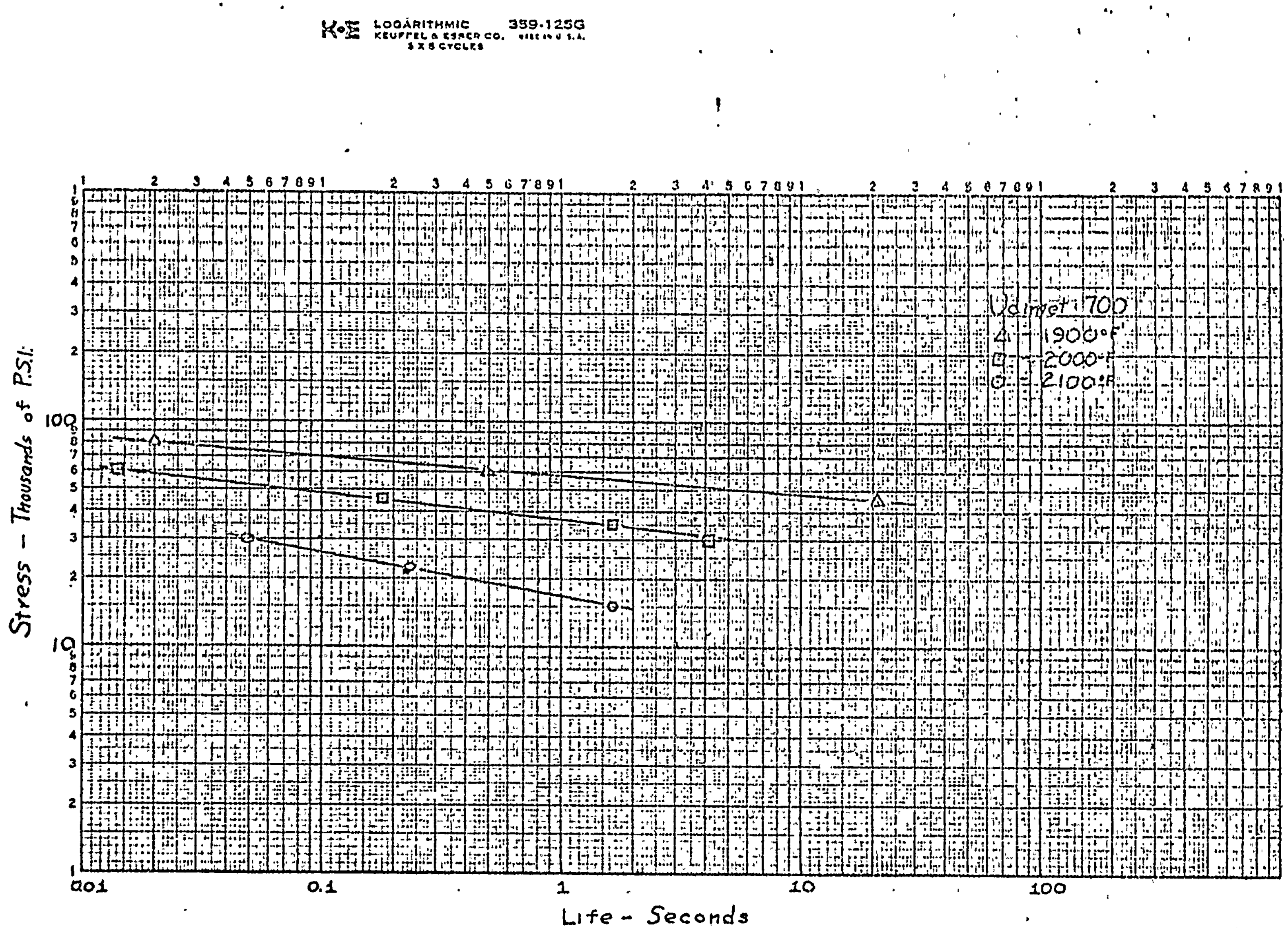

Figure 1: Log stress as a function of rupture life.

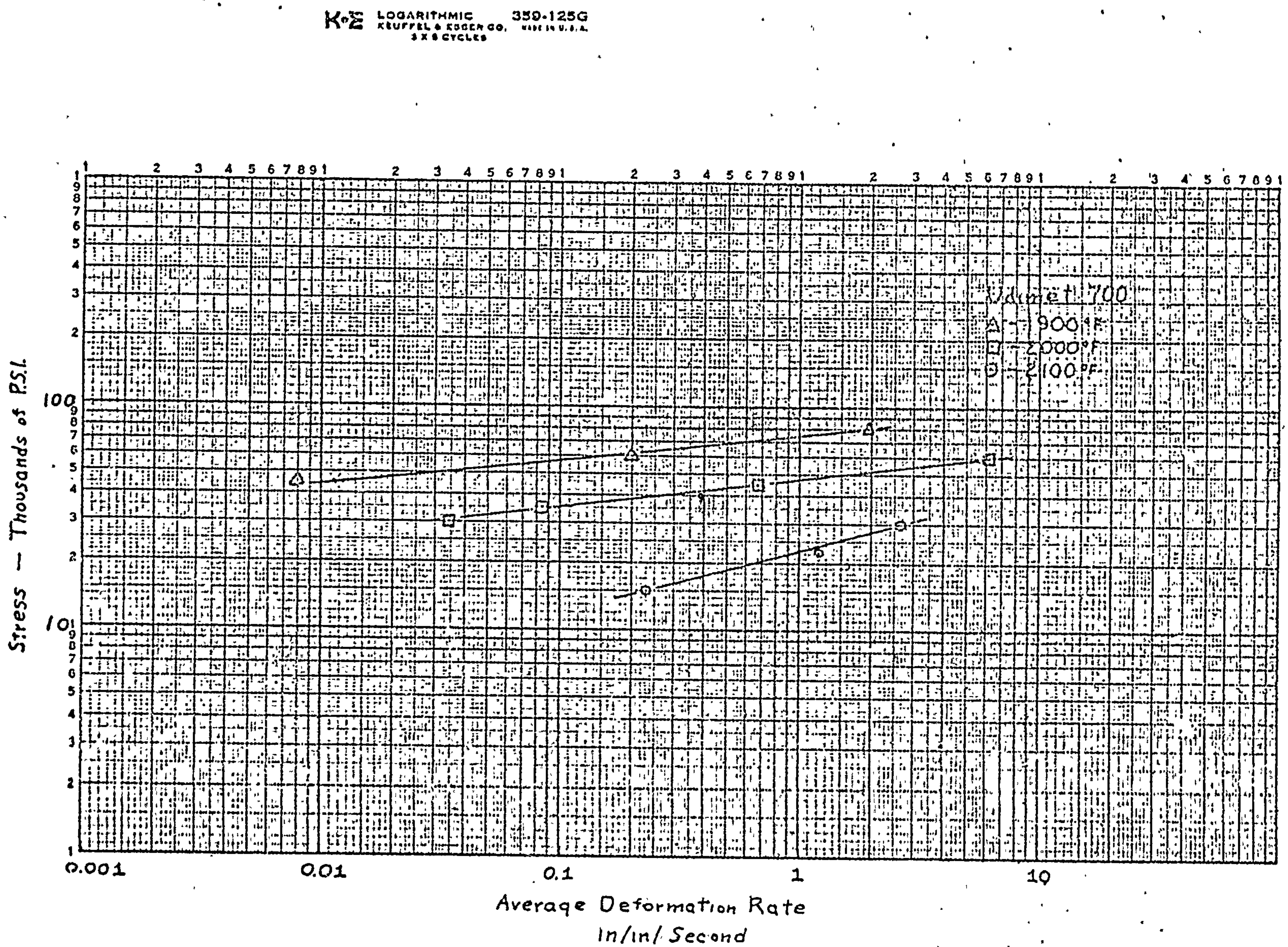

Figure 2: Log stress as a function of rate of deformation.

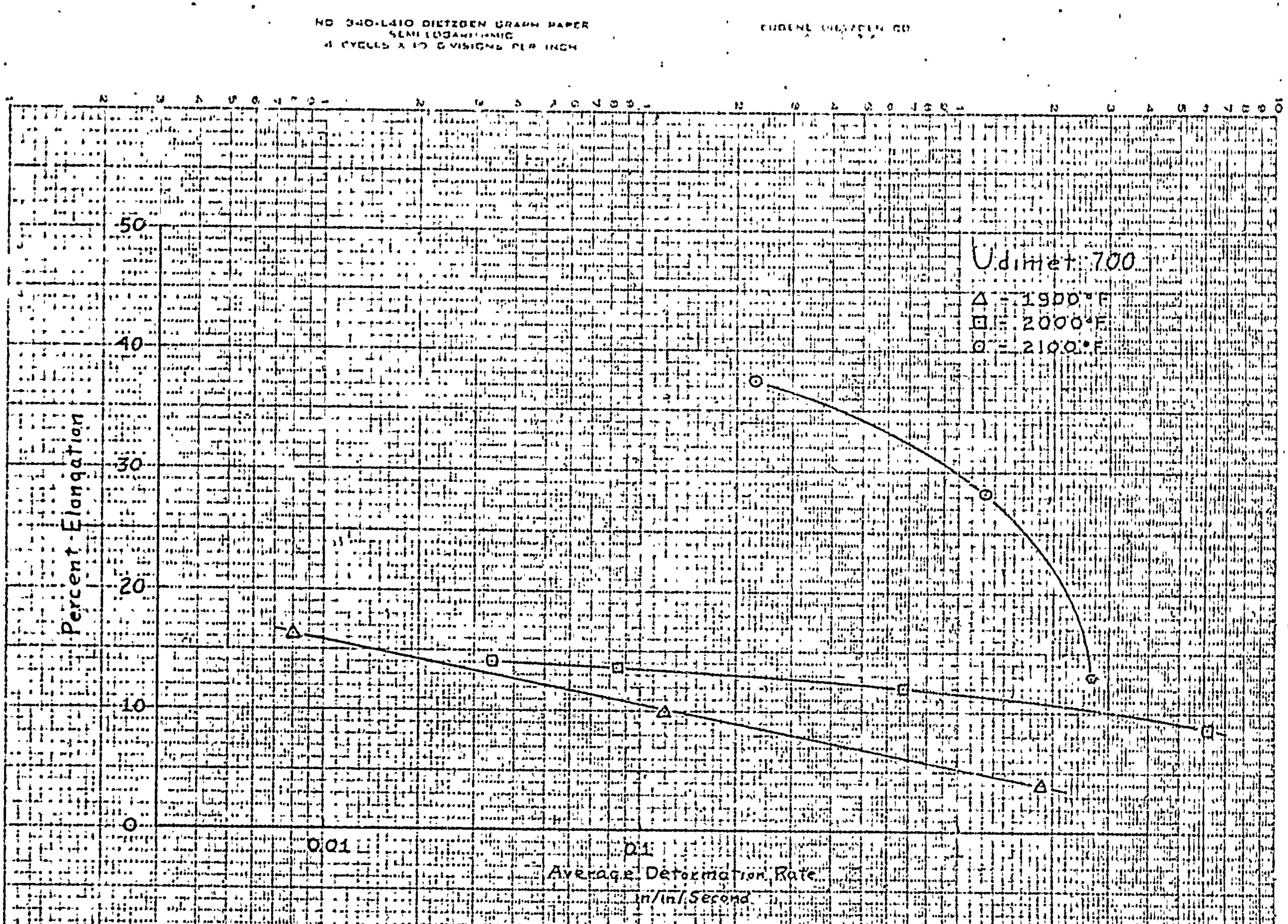

Figure 3: Elongation as a function of rate of deformation.

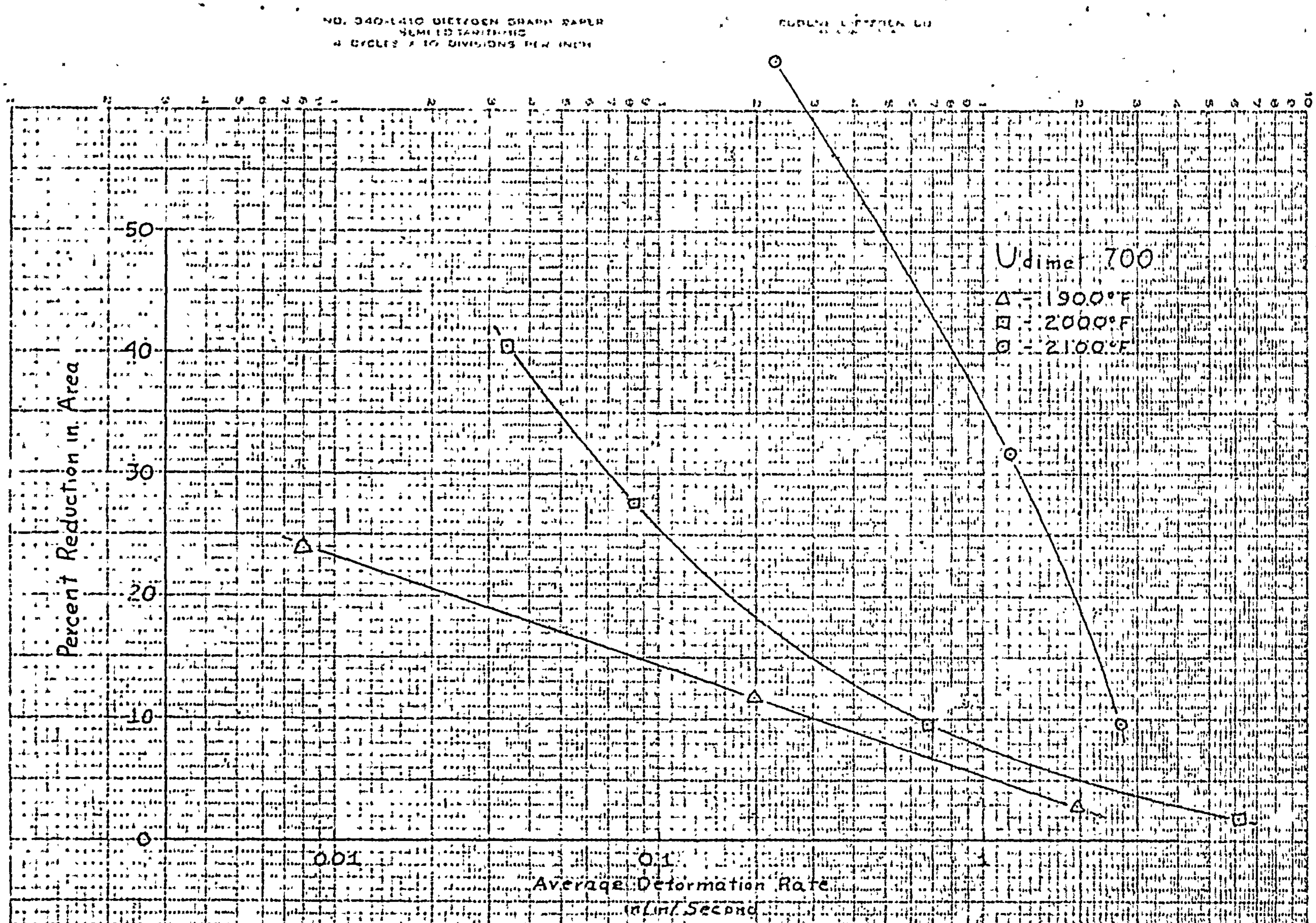

Figure 4. Reduction in area as a function of rate of deformation.

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